SSC-220

A LIMITED SURVEY OF SHIP STRUCTURAL DAMAGE

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SHIP STRUCTURE COMMITTEE

1971

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1971

In the continuing effort to maintain a high degree of structural reliability in new ship designs, the Ship Structure Committee has undertaken a project to identify areas of structural weakness through the systematic survey of vessel damage reports. From this identification structural improvement can easily follow.

This report contains a description and results of the first step in this systematic survey.

W. F. REA, III
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

SSC-220

Final Report

on

Project SR-189, "Ship Structure Reliability Analysis"

to the

Ship Structure Committee

A LIMITED SURVEY OF SHIP STRUCTURAL DAMAGE

by

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ABSTRACT

A limited investigation, conducted to determine the availability of data on ship casualties involving structural damage, revealed 824 applicable cases. A method was devised for reducing reported casualty data into a format adaptable to automatic tabulation and analysis. Collision with fixed and mobile structures was found to be the predominant cause of structural damage; heavy weather damage to the forefoot and forward weather deck also occurred with significant frequency. Patterns of damage frequency and location existed on a number of classes of ships. These have been interpreted to indicate how structures could be altered to reduce the damage sustained. Recommendations are made to continue the data collection and analysis program and to investigate more extensively the ways in which significant structural design information can be extracted.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

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INTRODUCTION

The goal of Project SR-189, "Ship Structure Reliability Analysis", is to conduct a survey of ship structural failures as related to types, frequency, and location in order to develop meaningful trends and to assess the possibility of eliminating or minimizing these failures and so improve structural reliability. This report, covering one year's effort, presents the data collected during the survey, together with conclusions and recommendations.

Briefly, the plan was to:

- Survey data sources to determine the amount and kinds of data available.
- Develop a data collection format compatible with the information available at each source.
- Collect available data from each source.
- Analyze the data collected.
- Report the results.

The ships represented in the data base are U. S. built, subsidized dry cargo ships, and a few MSC tankers. Modern ship designs differ from their World War II predecessors in many respects and modern ship steels gained broad acceptance in the mid-1950's; accordingly, only seagoing ships built after 1955 are included in this study.

SOURCES OF CASUALTY DATA

Ship structrual casualty data were obtained from the files of the U. S. Coast Guard (USCG), the Maritime Administration (MARAD), and the Military Sealift Command (MSC). This information comprises the data base from which analyses were made of structural damage. American Bureau of Shipping (ABS), U. S. Salvage Association, and Salvage Association of London reports were often a part of the files of the aforementioned agencies, and provided a major portion of the detailed information.

A few comments are in order regarding the kinds of information derived from each source:

A marine casualty must be reported to the Coast Guard whenever it results in damage to property in excess of $1,500.00, material damage affecting the seaworthiness or efficiency of the vessel, stranding or grounding, loss of life or injury with incapacitation in excess of 72 hours (46 CFR 97.01-1). In addition, a Report of Structural Damage, Collision Damage or Fire Damage (Form CG-2752) is submitted in cases of:

1. Class I Structural Failure: a failure which has weakened the main hull girder so that the vessel is lost or is in a dangerous condition.

2. Class II Structural Failure: a failure which does not endanger the vessel but involves the main hull structure at a location which experience has indicated is a potential source of dangerous failure.

3. Collision or Grounding with damage in excess of $1,500.00.

4. Fire or Explosion with damage in excess of $1,500.00.

Casualties which have been reported to the Coast Guard, but for which a Form 2752 has not been completed, were not included in this study.

MARAD files contain data on U. S. ships participating in the subsidy program. Records for subsidized voyages during the period 1966 through most of 1969 were available. Most of the earlier records have been destroyed but some data were obtained, on specific structural casualties occurring during the period 1961 through 1965, from other sources at MARAD. It is worthy of mention that some ships go in and out of subsidy, thus information on structural casualties occurring during out-of-subsidy operation may not be included in the files. The majority of the relevant data contained in MARAD files are in the form of investigative reports from one or more of the following organizations: U. S. Salvage Association, ABS, and Salvage Association of London.

Files of the MSC contain information on ships of their fleet from date of construction. The most useful sources of data found in these files were ABS survey reports.

In summary, direct access to structural casualty files was possible at the U. S. Coast Guard, MARAD and MSC. Information at these sources which became a part of the data base for this project comprised:

1. Cases for which a USCG Report of Structural Damage (Form CG 2752) was filed.
2. Cases for U. S. flag ship voyages subsidized by MARAD during the years 1961 through 1969. The relevant information in the MARAD case files is, for the most part, in the form of reports from U. S. Salvage, ABS, or Salvage Association of London.
3. Cases for MSC ships, from their date of construction, where ABS surveys were conducted.

CASUALTY DATA COLLECTION

At the outset of the project a tentative listing of information requirements was derived. After visiting the various potential data sources and perusing representative case files, a revised format was developed for use in the actual data collection effort. A copy of this form is shown in Figure 1.

In addition to a case number, the desired information is divided into ten basic categories:

1. Ship Data
2. Information Source
3. Circumstances
4. Cause
5. Disposition
6. Extent
7. Type of Failure
8. Type of Structure
9. Location
10. Remarks

Each basic category is then divided into subcategories with coded designations for each item and sub-item so as to permit the use of automatic data processing equipment. The entire data format as shown can be reduced to a single card for basic ship data and another card for the details of the specific structural failure. Thus for a given ship for which there are ten individual structural casualty cases, there would be eleven data cards.

Cost of repair is not included on the data form. For most of the cases investigated in this study, cost information was not available.

SCOPE OF STRUCTURAL CASUALTY DATA

The survey of structural casualty records resulted in a data base of 824 cases from 146 ships over the 15 years considered. It is difficult to determine the total number of U. S. Flag ships operated during that period. However, for comparison purposes, in mid-1969 there were 244 subsidized merchant ships of over 1000 gross tons in an operating status in the U. S. Flag Fleet. In addition MSC was operating 23 ships built after 1955.

Table 1 represents a breakdown of the data base by alleged cause of the casualty.

SHIP STRUCTURE RELIABILITY ANALYSIS

1. Case No.

SHIP DATA

2. Name
3. Off. No. ABS Rec. Other
4. Type of Vessel
5. Length
6. Breadth
7. Depth
8. Draft
9. Displacement tons
10. Year Built
11. Gross Ton.
12. Hull Material: 1 ☐ Steel; Other
13. No. of Holds
14. Year of Last Major Conversion
15. Type of Framing: 1 ☐ Longitudinal; 2 ☐ Transverse
16. Forebody Shape: 1 ☐ U; 2 ☐ V
17. Machinery Location: 1 ☐ Midships; 2 ☐ Aft
18. Superstructure Length
19. Superstructure Position
20. Bulb
21. C_b

INFORMATION SOURCE

22. Survey Date
23. Survey Location

24. a) Files: 1 ☐ USCG; 2 ☐ MARAD; 3 ☐ MSTS; 4 ☐ ABS; 5 ☐ USSALVAGE; Other

24. b) Survey report: 1 ☐ ABS; 2 ☐ USSALVAGE; 3 ☐ SALVAGE ASSOCIATION LONDON

CIRCUMSTANCES

25. Geog. Location OR 26. Route From 27. To

28. If unknown, failure found on annual survey 1 ☐ or drydocking 2 ☐

29. Ship Speed ________; 97 ☐ Anchored; 98 ☐ Moored; 99 ☐ In Drydock
30. Course ________; 999 ☐ Maneuvering
31. Load Conditions: 1 ☐ Ballast; 2 ☐ Partial; 3 ☐ Full Load
32. Date
33. Time
34. Air Temperature
35. Water Temperature
36. Wind Velocity
37. Wind Direction
38. Wave Height
39. Wave Length
40. Wave Direction

CAUSE

41. 1 ☐ Alleged 2 ☐ Proven

42. 1 ☐ Undetermined; 2 ☐ Heavy Weather; 3 ☐ Fire; 4 ☐ Flooding; 5 ☐ Grounding; 6 ☐ Collision; 7 ☐ Vibration or Shock; 8 ☐ Launching or Drydocking; 9 ☐ Cargo Shifting; 10 ☐ Wastage; 11 ☐ Explosion; 12 ☐ Ice; 13 ☐ Struck Object in Water

DISPOSITION

43. 1 ☐ Repaired at Sea; 2 ☐ Temporary Repair; 3 ☐ Port Repaired; 4 ☐ Repair at Next Port; 5 ☐ Repair at Next Drydocking

44. Previous Related Failure: 1 ☐ Same Failure; 2 ☐ Failure of Repair

EXTENT

45. 1 ☐ Catastrophic - Ship lost; 2 ☐ Major - Unable to proceed; 3 ☐ Minor - No delay-repair underway or at next port; 4 ☐ Local - Repair at Convenience

TYPE OF FAILURE

46. 1 ☐ Fracture; 2 ☐ Buckling; 3 ☐ Deformation (Bulging, Indentation, Setup); 4 ☐ Cracks; 5 ☐ Bending; 6 ☐ Failure of Weld; 7 ☐ Wastage

TYPE OF STRUCTURE

47. 1 ☐ Bulkhead (Incl. stiffening); 2 ☐ Deck (Incl. stiffening); 3 ☐ Shell (Incl. stiffening); 4 ☐ Bulwarks; 5 ☐ Floors; 6 ☐ Frames; 7 ☐ Plating; 8 ☐ Stem; 9 ☐ Stern Frame; 10 ☐ Bilge Keels; 11 ☐ Hatch Coaming; 12 ☐ Web Frames; Other

LOCATION

48. 1 ☐ Port; 2 ☐ Stbd; 3 ☐ Center
49. 1 ☐ Fwd; 2 ☐ Midships; 3 ☐ Aft
50. 1 ☐ Bottom; 2 ☐ Bilge; 3 ☐ Tanktop; 4 ☐ Side; 5 ☐ Weather Deck; 6 ☐ Interior Deck; 7 ☐ Superstructure; 8 ☐ Forecastle
51. Tank Nos.
52. Shell Plate Nos.
53. Frame Nos.

REMARKS 54.

Fig. 1 - Sample Data Form

Table 1 - Structural Casualty Data Base

ALLEGED CAUSE	NUMBER OF CASES	PERCENT OF TOTAL
Collisions with Piers, Quays	203	24.6
Collision with Vessels Alongside	179	21.7
Collisions with Locks	75	9.1
Collisions with Vessels Underway	66	8.0
Miscellaneous Collisions	27	3.3
Heavy Weather, Bottom Slamming	48	5.8
Heavy Weather, Forecastle and Weather Deck	23	2.8
Heavy Weather, Miscellaneous	17	2.1
Grounding	37	4.5
Struck Object in Water	14	1.7
Ice	7	1.0
Wastage	8	1.0
Fire	4	1.0
Launching or Dry Docking	2	1.0
Loading or Discharging Cargo	18	2.2
Miscellaneous	10	1.2
Undetermined	86	10.4
	824	100.0

Unfortunately, information on the dollar cost of damage was not generally available. The following discussion of the frequency-of-occurrence of a particular type of damage does not include cost. Frequency alone is not necessarily a measure of the severity of damage.

Various types of collision damage comprise the largest portion of the total cases -- 67%. Heavy weather causes, resulting in forefoot, forecastle and weather deck, or other miscellaneous damage, are the next largest general category -- 11% of the total. Cases for which the cause of structural damage was undetermined amounted to a little over 10%, and the remaining 12% fell into eight other categories as shown.

Collisions with piers, quays, and other fixed mooring structures comprise 203 cases or 25% of the total. Townsend and Hamrin found a similar trend for 100 ships surveyed over a period of a year (MARINE ENGINEERING/LOG, "Ship Damage", p.51, Vol. LXVIII, No. 11, October 1963). Collisions with locks comprised a little less than 10% of the total data base. Ships of some designs did not have any reported damage from this cause, suggesting that trade route considerations are a major factor.

Structural damage sustained through collisions with other vessels alongside also constitutes one of the major categories of casualties. Tugs assisting ships during mooring maneuvers, lighters, crane barges, and landing craft of various types were frequently parties in such collisions. A number of the reported casualties happened in Southeast Asia where cargo ships were unloading directly into landing craft and lighters.

Structural casualties of undetermined cause comprise 10.4% of the data. These casualties were all minor and generally were revealed in the course of routine surveys.

Thirty-seven groundings -- 4.5% of the data -- were reported. Of these, 31 involved deformation and buckling of various underwater portions of the ships, with only six cases of holing or fracturing of bottom plating. In 23 cases, of which four involved bow bulbs, only shell plating damage occurred. Five more cases involved internal structural members as well as shell plating, and nine additional cases included damage to bilge keels, plating, and internals. About one-third of the damaged areas were located in the forebody, about one-half around the midbody, and the remainder aft.

Three other categories of structural casualties warrant brief mention in this summary. Damage caused by striking objects in the water, for the most part was confined to ships' bottoms (9 out of 14 cases), indicating that the vessels either struck an unchartered object or actually grounded. Most of these cases involved deformation and buckling of the shell, or the shell and internal structural members.

Structural damage caused by ice was revealed during the survey. The total number of cases was small (7) but, since all occurred on tankers, this may be of special interest relative to Arctic ship design. It is worth mentioning here that, with one exception, damage attributed to ice was fairly extensive, involving numerous plates on the sides or bow and, in one case buckling of the main deck, internal bulkheads, and fracturing of framing and shell.

With four exceptions, the structural damage which occurred during loading and discharging operations is of only incidental interest. Four cases were found where structural damage resulted from filling tanks under pressure; three occurred on tankers and the fourth on a cargo ship. In one instance the problem was traced to a vent ball-check valve which was plugged with rust; whether the remainder resulted from inadequate vent size or through carelessness, is not known.

Figure 2 shows the longitudinal and vertical location of damage for all cases and all ships on one typical profile. The transverse location is not indicated but most casualties affected primarily the shell or contiguous structure. Damage indicated on the base line in this figure was generally due to slamming and concentrated at the centerline.

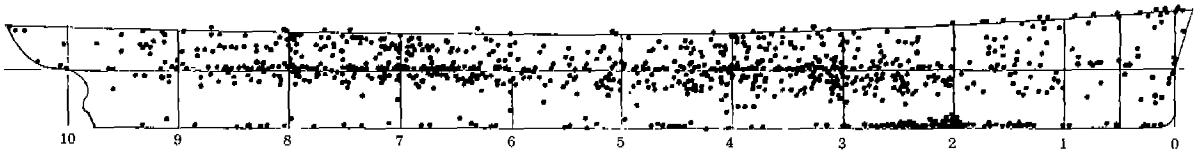


Fig. 2 - Longitudinal and Vertical Location of Damage, All Causes - All Ships

The relative localization of ship damage is listed in Table 2. The statistical center of damage is forward of amidships and generally the damage occurs in the outboard portions of the hull. It also appears that certain types of structure are more susceptible to damage as shown in Table 3. Here 58% of the occurrences were in the shell and stiffeners and 19% in the framing. Table 4 indicates that the preponderance of casualties (79%) resulted in deformation.

Table 2 - General Distribution of Structural Damage

PORT	49%	FORWARD	34%
CENTER	9%	MIDSHIPS	40%
STARBOARD	42%	AFT	26%

Table 3 - Distribution of Failures by Structural Elements

Type of Structure	% Occurrence
Bulkhead	5
Deck	6
Shell	58
Bulwark	3
Floor	2
Framing	19
Plating	1
Stem	2
Bilge Keel	1
Web Frame	2
Remainder	1

Table 4 - Distribution by Type of Failure

Type of Failure	% Occurence
Fracture	3
Buckling	1
Deformation	79
Wastage	1
Deformation and Buckling	7
Deformation, Buckling, and Fracture	1
Deformation and Fracture	5
Cracks, Bending, Weld Failure, Wire Cutting, Holing	3

STRUCTURAL CASUALTY PROBLEM AREAS

Analysis of the structural casualty data revealed three areas which warrant detailed discussion. While these areas are not intended to be all-inclusive, they are presented to indicate the value of the program in identifying and localizing problems. Some need added research while others need to be brought to the attention of designers for refinement of design details. These three areas are collision damage, slamming damage, and forecastle and weather deck damage.

Some 13 specific ship design classes have been selected for a more detailed investigation of these three problem areas. Ships of each of these classes have sustained damage attributed to one or more of the problem areas as indicated in Table 5.

Table 5 - Classes of Ships Selected for Detailed Damage Analysis

Design	Ships In Class	Delivery Dates	Approximate Speed, Kts.	Machinery Location	DAMAGE CASES ANALYZED		
					Collision	Slamming	Weather
A	11	1962-63	21	Midship	48	14	4
B	8	1960-62	19	Midship	30	11	
C	8	1961-63	18	Aft	16	7	
D	4	1960-61	18	Midship	11	4	
E	5	1964-66	21	Midship	18	2	
F	6	1962-63	20	Midship	18	2	
G	6	1962-63	20	Midship	30	2	1
H	2	1966	23	Midship		1	
I	26	1960-65	18	Aft	145	3	
J	6	1964-65	23	Midship	31	1	7
K	5	1961-65	20	Midship	16	1	5
M	1	1958	16	Aft			5
N	2	1961	20	Midship			1

Collision Damage

Ten cargo ship designs were selected for collision damage analysis. Ships of these ten designs were involved in almost 80% of the casualties related to collisions with piers, vessels alongside, and locks.

Three specific factors were investigated:

1. longitudinal extent and location of damage
2. vertical extent and location of damage
3. type of damage.

The following paragraphs cover analyses of each of these factors.

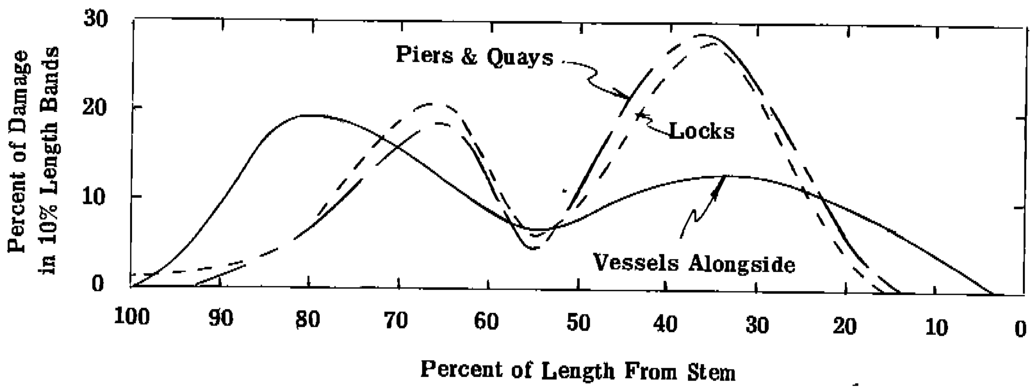


Fig. 3 - Longitudinal Distribution of Collision Damage

Using the survey data, and basic information for the respective ship designs, plots were derived of the longitudinal extent and location of collision damage. Collisions with piers, vessels alongside, and locks were treated separately in order to ascertain whether characteristic differences existed between these types of damage.

Comparisons of individual ship results by cause did not show any marked differences so they were combined. Figure 3 shows the longitudinal distribution of damage due to striking piers and quays, damage from collisions with vessels alongside, and damage due to striking locks.

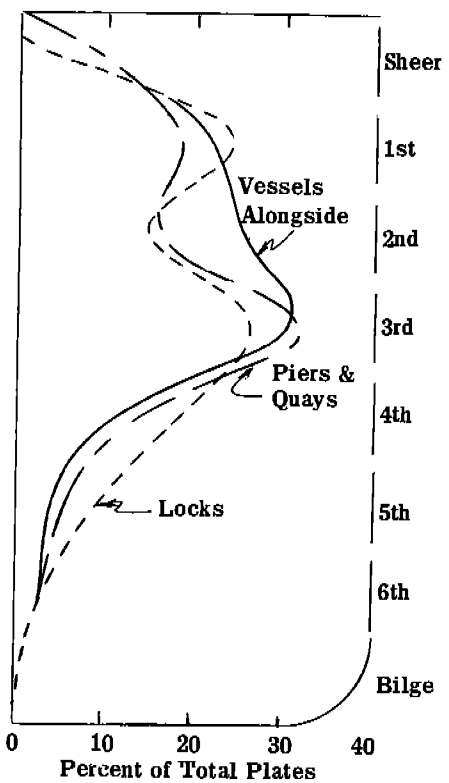


Fig. 4 - Vertical Distribution of Collision Damage

The data for the same ten ship designs provided the basis for an evaluation of vertical extent and location of damage related to the same three causes. Information from the survey data sheets on individual damaged plates was tabulated for each design. This information was then totaled and analyzed to determing trends in vertical distribution of damage. Tables 6, 7, and 8 summarize the results for pier, vessel alongside, and lock collisions respectively and the results are displayed graphically in Figure 4.

It can be noted from Figures 3 and 4 that the longitudinal and vertical damage distributions from collisions with piers and locks are markedly similar whereas collisions with vessels alongside result in distributions with different characteristics. Pier and quay collisions tend to cause somewhat greater damage at the waterline than do collisions with locks. Lock collisions tend to produce more damage just below the sheer strake which is probably related to accidents occurring when ships are on the low-water side of the lock.

Table 6 - Vertical Distribution of Damage Due to Striking Piers

Number of Plates Involved Per Strake

Design	Cases per Class	Sheer Strake	Strake Below Sheer Strake					
			1st	2nd	3rd	4th	5th	6th
A	17	-	-	-	3	18	11	-
B	16	-	2	22	16	1	-	-
C	11	-	3	11	10	1	-	-
D	8	-	2	18	26	1	-	-
E	7	-	-	-	5	8	2	-
F	9	10	12	5	-	-	-	-
G	19	-	-	2	7	24	7	3
I	52	30	54	-	57	1	1	11
J	10	-	3	9	5	-	-	-
K	9	-	-	-	3	8	4	-
TOTALS	158	40	76	67	132	62	25	14
PERCENT OF PLATES		9.6	18.3	16.1	31.7	14.9	6.0	3.4

Table 7 - Vertical Distribution of Damage From Vessels Alongside

Number of Plates Involved Per Strake

Design	Cases per Class	Sheer Strake	Strake Below Sheer Strake						Turn of Bilge
			1st	2nd	3rd	4th	5th	6th	
A	13	1	1	1	6	28	9	3	-
B	11	2	9	46	28	4	-	-	-
C	5	-	4	15	16	4	-	-	-
D	3	-	1	2	-	-	-	-	2
E	4	-	-	-	1	4	-	-	-
F	8	5	4	3	1	-	-	-	-
G	11	1	-	-	4	15	9	-	-
I	60	13	91	14	81	3	3	16	-
J	11	-	23	70	44	7	-	-	-
K	7	-	-	-	2	5	2	-	-
TOTALS	133	22	133	151	183	70	23	19	2
PERCENT OF PLATES		3.6	22.2	25.0	30.4	11.6	3.8	3.1	0.3

Table 8 - Vertical Distribution of Damage Due to Striking Locks

Number of Plates Involved Per Strake

Design	Cases per Class	Sheer Strake	Strake Below Sheer Strake					
			1st	2nd	3rd	4th	5th	6th
A	18	-	1	3	7	20	12	4
B	3	-	2	5	4	-	-	-
E	7	-	-	-	7	7	1	-
F	1	1	3	-	-	-	-	-
I	33	5	22	-	17	1	1	-
J	10	1	8	14	4	-	-	-
TOTALS	72	7	36	22	39	28	14	4
PERCENT OF PLATES		4.7	24.0	14.7	26.0	18.7	9.2	2.7

The longitudinal and vertical damage distributions for collisions with piers, quays, and locks have been combined to produce the contours of Figure 5. These are contours of equal damage probability; they are labelled with an arbitrary scale ranging from 1 to 10, i.e., from lowest to highest probability of damage in the region of the hull along the lines of the contours. A similar set of contours, based on data from collisions with vessels alongside, is given in Figure 6.

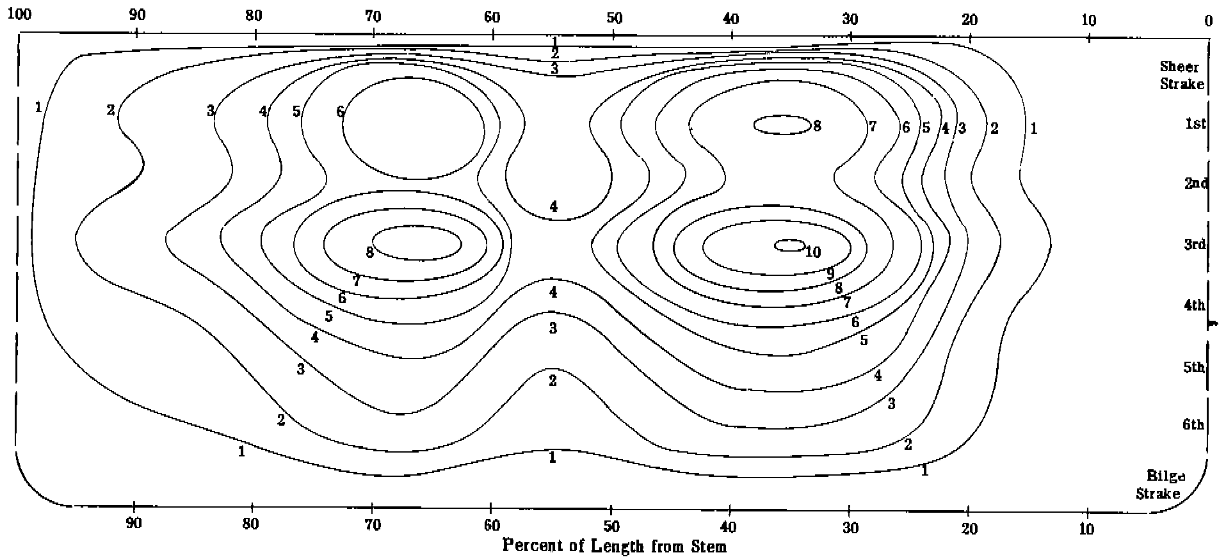


Fig. 5 - Damage Location Probability Contours From Collisions With Piers, Quays, and Locks

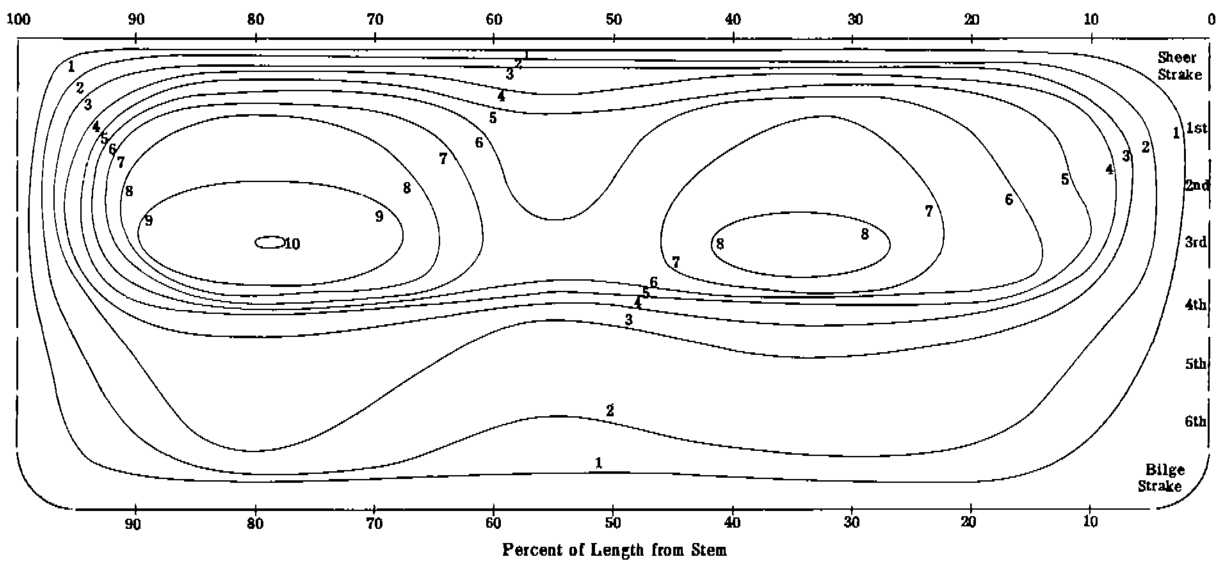


Fig. 6 - Damage Location Probability Contours From Collisions With Vessels Alongside

Table 9 - Failures Resulting From Striking Piers

Design	Total Cases	Shell Deformation Only	Shell & Internal Deformation	Deformation, Buckling	Shell Fracture	Internal Fracture	Misc.
A	17	8	4	3	–	–	2
B	16	5	11	–	–	–	–
C	11	6	5	–	–	–	–
D	8	1	7	–	–	–	–
E	7	5	1	1	–	–	–
F	9	3	6	–	–	–	–
G	19	8	10	1	–	–	–
I	52	33	10	9	–	–	–
J	10	5	4	1	–	–	–
K	9	5	3	–	–	1	–
TOTALS	158	79	61	15	0	1	2

Table 10 - Failures Resulting From Striking Vessels Alongside

Design	Total Cases	Shell Deformation Only	Shell & Internal Deformation	Deformation, Buckling	Shell Fracture	Internal Fracture	Misc.
A	13	7	4	1	–	1	–
B	11	5	4	1	1	–	–
C	5	3	2	–	–	–	–
D	3	1	2	–	–	–	–
E	4	3	1	–	–	–	–
F	8	6	–	–	1	1	–
G	11	8	3	–	–	–	–
I	60	45	8	5	1	1	–
J	11	10	1	–	–	–	–
K	7	7	–	–	–	–	–
TOTALS	133	95	25	7	3	3	0

Table 11 - Failures Resulting From Striking Locks

Design	Total Cases	Shell Deformation Only	Shell & Internal Deformation	Deformation, Buckling	Shell Fracture	Internal Fracture	Misc.
A	18	11	5	2	–	–	–
B	3	1	1	1	–	–	–
E	7	4	3	–	–	–	–
F	1	0	1	–	–	–	–
I	33	10	21	1	–	1	–
J	10	3	7	–	–	–	–
TOTALS	72	29	38	4	0	1	0

The Ship Structure Reliability Data Sheet (Figure 1) lists seven types of failures: fracture, buckling, deformation, cracks, bending, failure of weld, and wastage. As a practical matter, a given case may involve more than one of these categories in conjunction with one or more structural members. Analysis of the failure type data for the ten cargo ship designs involved summarizing the occurrences of each type of failure, taking into account the practical aspects of the problem mentioned above. Tables 9, 10, and 11 summarize these results.

As can be seen, the vast majority of the cases, regardless of cause, consisted of deformation of just the shell plating or the shell plating and internal structural members. Indeed, out of 363 cases there were only 26 cases involving deformation and buckling of internal structural members and only 8 involving fractured structures. Of the 8 fracture cases, only 3 involved shell plating; less than 1% of the total.

The relative occurrence of collision damage with piers in U. S. and foreign ports was investigated. Thirty nine percent of the collisions with piers occurred in U. S. ports and 61% in foreign ports. While a much higher percentage of these collisions with piers occurred in foreign ports, one must be careful not to make improper assumptions about ship handling or pier construction. For instance, it was not possible to determine the relative number of ports of call between the U. S. and foreign countries. Cost information for collision damage was not obtained during the survey.

Heavy Weather Slamming Damage

The total number of occurrences of bottom slamming damage amounted to 48. All occurred on dry cargo ship designs as shown in Table 12. Since the number of casualties found during the survey was limited by the availability of records from each source of data, the number of casualties shown does not necessarily represent all of the occurrences of slamming damage for the ship designs listed.

The longitudinal extent and location of slamming damage, as a function of ship length, is shown in Figure 7 for each ship of each design. In general, this type of structural damage is centered at approximately 20% of the length from the bow and extends as far forward as 5% of the length from the bow and as far aft as 35%. Figure 8 shows the distribution of slamming damage relative to ship length.

Table 12 - Summary of Bottom Slamming Damage

Design	Ships in Class	Casualties in Data Base	Casualties per Total Ships	Ships Having Casualties	Casualties per Ship Involved
A	11	14	1.27	11	1.27
B	8	11	1.37	6	1.83
C	8	7	0.88	5	1.40
D	4	4	1.00	3	0.75
E	5	2	0.40	2	1.00
F	6	2	0.33	2	1.00
G	6	2	0.33	2	1.00
H	2	1	0.50	1	1.00
I	26	3	0.12	3	1.00
J	6	1	0.17	1	1.00
K	5	1	0.20	1	1.00
TOTALS	87	48	0.55	37	1.30

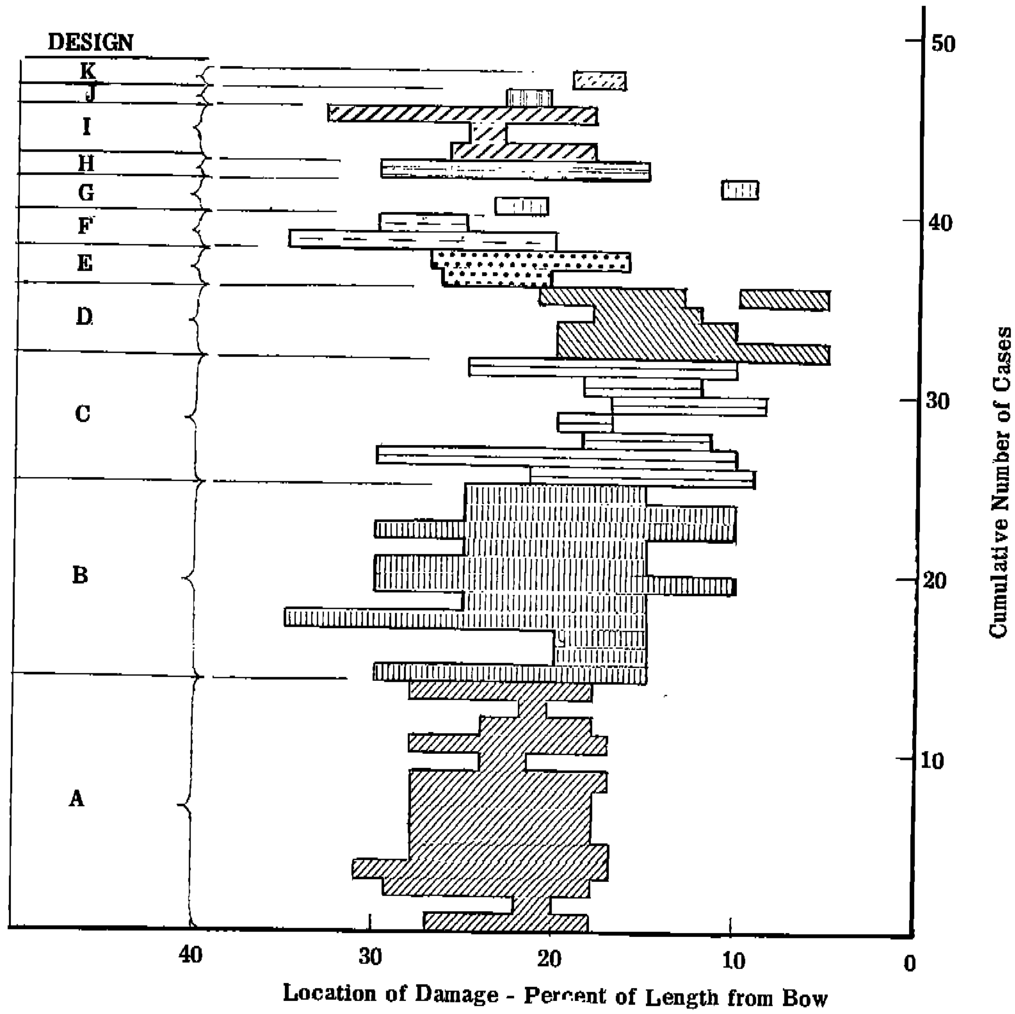


Fig. 7 - Extent and Location of Slamming Damage for Various Cargo Ship Designs

The most prevalent type of failure was deformation of hull plating, in particular the flat keel and A-strakes port and starboard. A smaller number of cases involved additional damage to other strakes, floors, and internal structural members. Further details will be discussed in the treatment of individual designs.

All 11 ships of Design 'A' encountered slamming damage, at one time or another; a total of 14 cases were reported. They encountered the reported damage while operating in the North Atlantic between 1963 and 1966. Eight of the 11 ships suffered damage between the months of November and March, one in August and for the remaining two casualties no dates were given. Four of the casualties involved the flat keel and A-strakes port and starboard, one additional case involved the keel plate, A-strakes and floors; the remaining 9 cases involved damage to combinations of the flat keel, floors, and shell extending out to the C-strake.

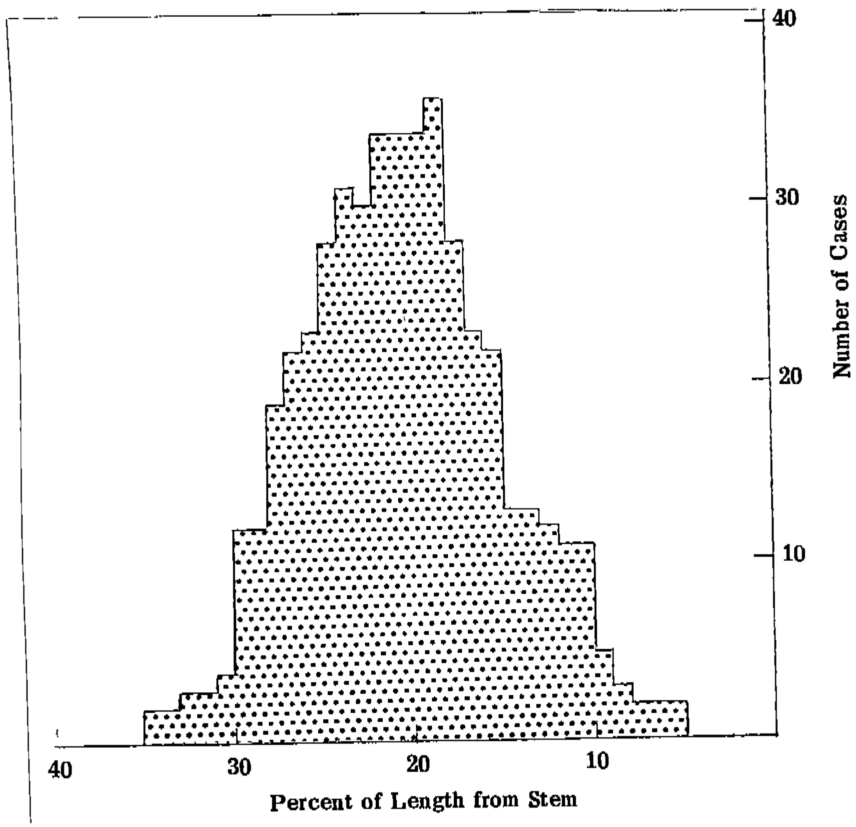


Fig. 8 - Cumulative Extent and Location of Slamming Damage

The body plan of Design 'A' indicates generally U-shaped forebody sections typical of many U. S. cargo ship designs. Figure 9 shows a sketch of the structural arrangement in the area of interest. Although details were not available, it was ascertained that all ships in this class sustained damage of the type described above during their first year of operation. After recognizing this slamming damage problem, additional longitudinals were added on all ships of this class. No further casualties were experienced.

Six of the eight ships of Design 'B' have incurred 11 cases of slamming damage. Six cases of damage resulted from operations in the North Atlantic during the winter months. Three of the casualties occurred in the South Atlantic during July and August (winter), one occurred in the Indian Ocean in March, and the date of one casualty was not given. Eight cases involved the flat keel and A-strakes, port and starboard, two involved the flat keel alone and, in one case just the A-strake. In 10 cases the hull plating was deformed and one case involved minor cracking of the keel plate.

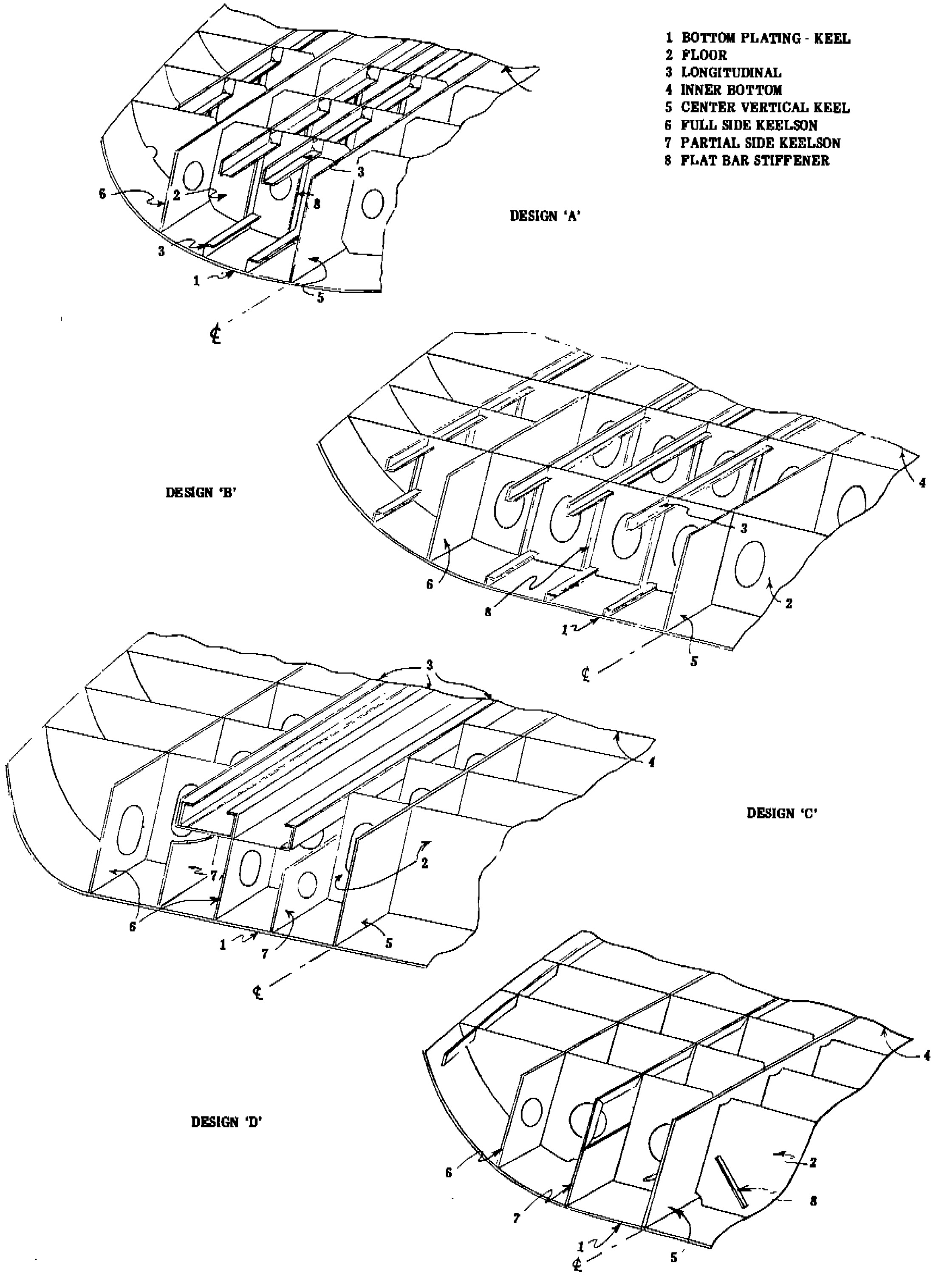


Fig. 9 - Structural Details in Area of Bottom Damage

Figure 9 shows a sketch of the structural arrangements of Design 'B' in the major region of failures. Over a period of years structural modifications were made to some of the ships in this class in order to obviate slamming damage. Details as to exactly what improvements were made, and whether they were successful, have not been ascertained.

Five of the eight ships of Design 'C' suffered seven slamming damage casualties. Six of the casualties occurred in the Atlantic and one in the Pacific. Five occurred during winter months and two in the summer and fall months. The location and extent of the slamming damage on ships of this design is interesting in that it generally occurred a little farther forward than was the case with all but one of the remaining designs (see Figure 7). The center of damage is approximately 16% of the length from the bow and is generally confined to the area between 10% and 20% of the length.

All but one of the casualties to ships of Design 'C' involved the flat keel and A-strakes, port and starboard; the remaining case involved damage to the flat keel. All cases resulted in deformation of the plating. Figure 9 shows structural details in this area. Some structural modifications have been made to ships in this class but details of these modifications and their relative success in reducing slamming damage were not found.

Design 'D' comprises four cargo ships, three of which incurred slamming damage. Three of the casualties occurred in the North Atlantic, two in the winter and one in April; the fourth casualty occurred in the Pacific during the winter. The location and extent of this damage is also interesting since damage was confined generally to the forward 10% to 20% of the length and consisted primarily of deformation of the flat keel and A-strakes, port and starboard in the area shown in Figure 9. No information was obtained regarding structural modification to these ships.

Designs 'E', 'F', 'G', and 'H' are similar and incurred slamming damage on from 30% to 50% of the ships in each class. The slamming damage to Designs 'E' and 'F' occurred during the winter in the Atlantic and, to Designs 'G' and 'H', during the winter in the Pacific and Mediterranean respectively. Six of the seven casualties involved typical deformation of the flat keel and A-strakes, port and starboard, as well as internals; the seventh, on Design 'G' resulted in a fracture of the E-strake just above the inner bottom.

Designs 'I', 'J', and 'K' incurred heavy weather slamming damage on less than one-third of the ships per class. Five of the six casualties occurred during winter months in either the Pacific or Atlantic. Three of the casualties for Design 'I' involved deformation of plates in one or more strakes both port and starboard. The two casualties to Designs 'J' and 'K' involved deformation of the flat keel and A-strake.

Designs 'A' through 'D' are classes for which reasonable proof has been obtained of susceptibility to damage from slamming. For each of these designs all or most of the ships have suffered slamming damage at one time or another. Most probably, if more complete records were available, additional cases would be added to those already revealed in this survey.

The remaining eight designs, 'E' through 'K', apparently fall into two additional categories relative to structural resistance to slamming damage. These categories are:

- Those designs having sustained slamming damage but not to the extent that they can reasonably be considered as being structurally deficient (Designs 'E', 'F', 'G', and 'H');

- Those designs having sustained slamming damage under extenuating circumstances where structural sufficiency is difficult to evaluate (Designs 'I', 'J', and 'K').

Further monitoring of structural casualty data should provide a greater insight into the relationship between structural sufficiency and susceptibility to damage from slamming.

Precise details as to the circumstances under which the casualties occurred are lacking. Other than the fact that the majority of the cases occurred during winter months on various trade routes, little additional data could be found. Ship speeds, loading conditions, and other environmental details at the time of the casualties were, in most instances, either unreported or stated in very qualitative terms such as "mountainous seas".

None of the slamming casualties resulted in catastrophic or 'unable to proceed' damage. Indeed, most of the cases were minor to the extent that some of the ships were not taken out of service specifically to repair that damage. Some cost data were obtained in the instance of slamming damage to ships. The average cost of repairs was found to be $27,700 with a spread from $4800 to $68,700.

Heavy Weather Damage, Forecastle and Weather Deck

The next most prevalent form of heavy weather casualty uncovered during the survey was damage to structural components on the weather deck. Out of 23 cases 17 occurred in the area of the forecastle and the remainder at locations farther aft. Most involved damage to bulwarks and some to decks and internal structural members as well.

Table 13 summarizes the information for six specific designs. All of the designs are cargo ships with the exception of Design 'M' which is a tanker.

Table 13 - Summary of Weather Deck Damages in Heavy Weather

Design	Number of Ships in Class	Number of Casualties	Number of Ships Having Casualties	Location Forecastle	Location Aft
J	6	7	4	6	1
K	5	5	3	5	-
M	1	5	1	5	-
A	11	4	3	1	3
G	6	1	1	-	1
N	2	1	1	-	1
TOTALS	31	23	13	17	6

Four of the designs warrant further discussion.

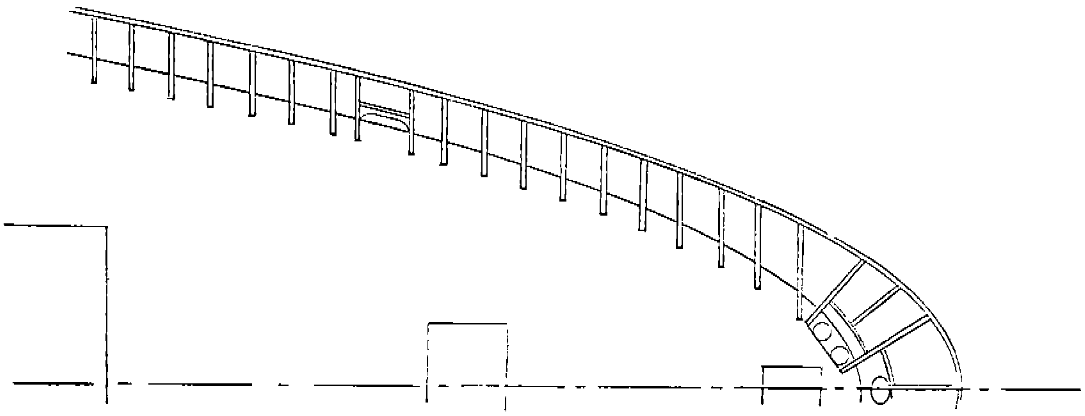
Four of the six ships of Design 'J' had at least seven casualties, six occurring on the forecastle and one involving bulwarks farther aft. The types of structural failures symtomatic of this design are:

1. forecastle deck torn or deformed;
2. bulwark and bulwark brackets and stiffeners fractured, buckled, and deformed;
3. internal beams, longitudinals, and frames deformed or fractured.

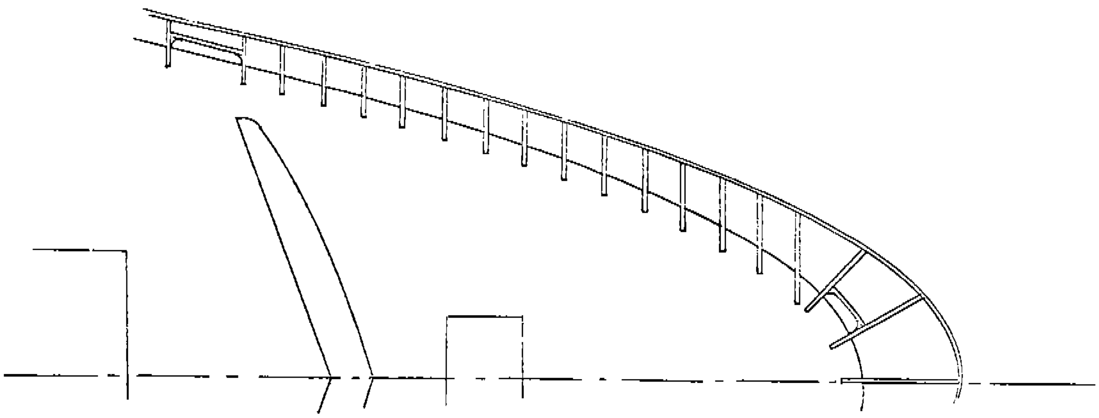
Most of this damage occurred within the forward 20 to 30 feet of the forecastle in the region shown in Figure 10.

Three of the five ships of Design 'K' sustained a total of five casualties in the forecastle area. For the most part the damage occurred in an area between 6 feet and 35 feet aft of the forecastle head. Bulwark brackets and knees as well as deck plating, deck beams, and girders were deformed or fractured in the area shown in Figure 10.

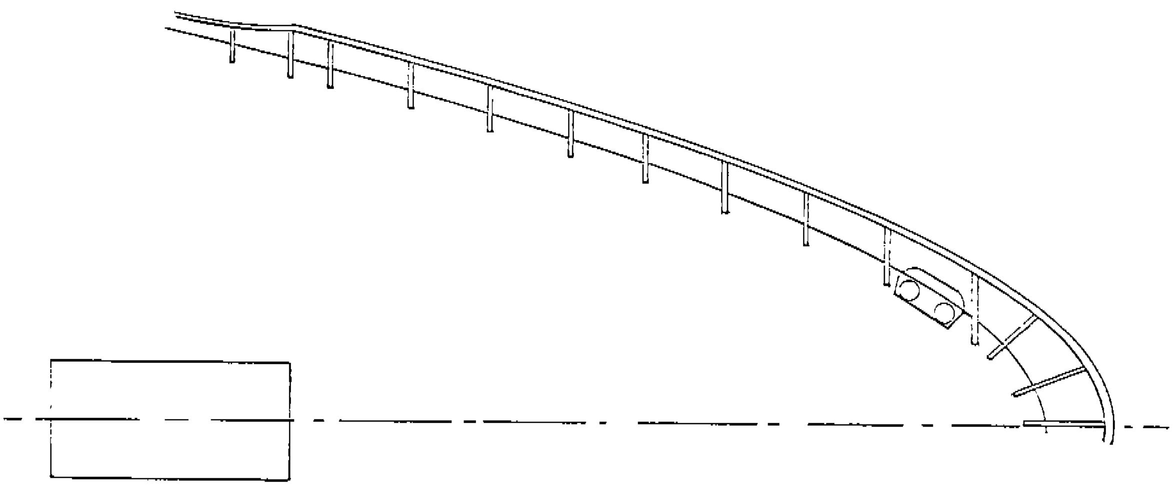
Design 'M' is a tanker which has had five structural casualties in the area of the forecastle. Three of the cases involved only fracturing of bulwark brackets. One case, however, included deformation and fracture of the bulwarks, deck plating, and internal structural members. In this instance the bulwarks were set out and the deck plating was set up, indicating that for this casualty the damage resulted from moving water trapped on the forecastle. The remaining case involved fractured and deformed hull plates in the vicinity of the hawse pipe both port and starboard. Figure 10 also shows the forecastle arrangement of this ship.



Design 'J'



Design 'K'



Design 'M'

Fig. 10 - Arrangement of Forecastle and Bulwark

Design 'A' also sustained weather deck damage which is of interest. Three of the 11 ships in this class had a total of four casualties. One casualty involved damage to the forecastle and appears to be an isolated instance. The other three casualties, however, involved damage to bulwarks much farther aft, by hatch numbers 3, 5, and 6. In one instance 60 feet of bulwark was torn away and missing; in another 30 feet of bulwark was seriously distorted along with the fracturing of a number of bulwark brackets. Since side bulwark damage occurred relatively infrequently and, since one-half of the occurrences were on ships of this design, it is suspected that the bulwark arrangement on Design 'A' is marginally adequate at best. Figure 11 shows a sketch of the bulwark structural design for this ship in the area where the damage occurred.

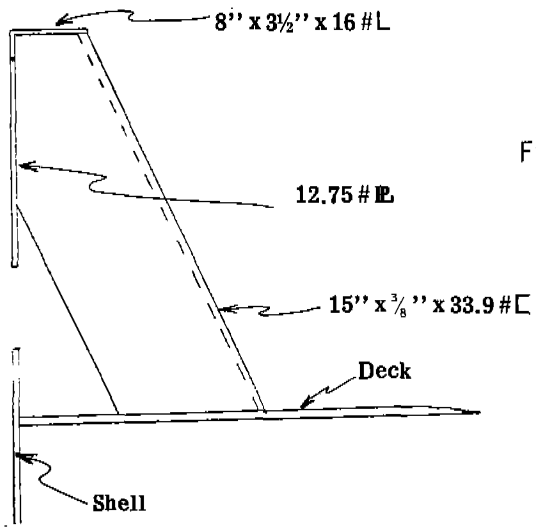


Fig. 11 - Sketch of Bulwark, Design 'A'

INTERPRETATION OF STRUCTURAL CASUALTY DATA

In the limited survey of ship casualties covered by this report it is not possible to extract all of the meaningful information which may be contained in the accumulated data. Yet there have evolved a number of trends which give some insight into what may be learned by more exhaustive analysis of these data or from more extensive surveys of this type. Additionally the limited analyses which have been made can be interpreted to indicate a logical path to follow in future research, development, and design projects aimed at improved ship structures.

First it is important to remember that a ship casualty involves both a cause and an effect -- and the two are not always separable. Furthermore both cause and effect may each comprise a number of factors related to the environment, operational techniques, economics, and chance, as well as to the many complex elements which enter into the design of a modern merchant ship.

Any interpretation of ship casualty data which has as its goal the improvement of one aspect of ship design, such as ship structures, must necessarily take into consideration all of the factors involved.

A cogent example of this cause and effect relationship is found in analyzing structural damage resulting from collisions. A collision may be caused by environmental disturbances over which no control can be exercised such as high wind or unexpectedly strong current. It can be caused by improper ship handling by the crew, by pilots and dockmasters, or by the crews of vessels alongside. The cause may also be laid to the designer and builder who provide inadequate maneuvering control, or to malfunctioning of critical equipment.

The effect of a collision, as far as this study is concerned, is damage to the structure of the ship. The pertinent question is then whether the ship structural designer can do anything to ameliorate the damage resulting from collisions. The survey data can be interpreted to show that, to some extent, he can. Referring back to the contours of damage location probability given in Figures 5 and 6 it is possible to make some observations related to the cause and the effect of the collisions which produced these results.

Collisions with both fixed and mobile structures caused damage most frequently in the region of the load waterline. Collisions with fixed structures also incurred a fair amount of damage just below the sheer strake; both the waterline and above-waterline damage concentrations centered primarily at one-third of the length and secondarily at two-thirds of the length from the stern. These concentrations of damage location could indicate that collisions with fixed structures occurred most often when the ships were moving forward and that contact was made in the region of maximum hull curvature. Damage from collisions with vessels alongside centered in about the same region of the waterline forward, but the after damage centered at about 80% of the length from the stem. Also damage from mobile structures occurred with greater frequency aft than forward indicating that either the damaged ship was moving astern or that the other party to the collision was the culprit. It might be mentioned that this after damage center is a favored region for pushing with tugs when moving away from a pier.

The foregoing discussion relates primarily to a surmise of causative factors in collisions as indicated by the survey data. On the other hand these damage location probability contours could be interpreted as evidence of a failure of the ship structure to withstand collisions with fixed and mobile structures. Both sets of contours have a marked similarity in this respect in that the damage occurred most frequently at the weakest points of the hull structure.

A conventional hull girder is designed with major strength members along the upper and lower extremities, i.e., the main deck and sheer strake and the double bottom and bilge strake. Midship shell plating is designed heavier to resist bending. The fore and aft peak tanks, with their heavy internal structures, provide a great deal of strength to the forward and after 5% of the length. If this total strength pattern is superimposed on the contours of Figures 5 and 6 it can be seen that the probability of sustaining damage is inversely proportional to the strength of a conventional hull design.

Whether it is economical to attempt to design a ship structure to resist or ameliorate damage from collisions is somewhat questionable. However the data obtained in this survey would indicate that if such an attempt is made it would logically include installation of stringers along the shell at the waterline and web frames in the regions of one-third and three-quarters of the length from the bow.

Although design to reduce collision damage may be open to question there appears to be no doubt that structural design to reduce heavy weather damage is mandatory. This applies both to slamming damage and damage to the forecastle and weather deck. The basic cause of heavy weather casualties is obviously the environment. The operator has some control over both cause and effect; he can reroute the ship to avoid heavy weather and he can slow down to lessen the chance of sustaining damage. However both of these control measures have an economic connotation in that they involve the loss of time and a corresponding reduction of revenue. Thus it devolves upon the designer to provide a vehicle which offers maximum protection against heavy weather damage.

The likelihood of slamming and of taking green water over the forecastle and weather deck is also related to the hull form and the configuration of the above water body of the ship. Weather deck damage can also be avoided to some extent by the erection of protective barriers. If it is assumed that everything possible has been done to minimize the hydraulic impacts it then is necessary to provide a structure to withstand the loadings which may be imposed.

The survey data alone do not reveal much information on what can be done structurally as a palliative for slamming damage. However they do show the spread of from 10% to 30% of the length over which the damage extended and that damage was generally confined to the flat keel, A-strakes, and floors in this region. This shows the limit of the area over which structural strength might be increased. Furthermore, if details were available on the modifications made to Design 'A', it would be possible to point to one structural arrangment which apparently provided satisfactory resistance to slamming damage on one class of ships.

From the meager data available on forecastle deck damage, only tentative conclusions can be drawn as to what structural modifications might be warranted. Apparently conventional bulwark structures are adequate to withstand the hydraulic impact incurred as the bow pitches downward. The major damage seems to have been incurred after green water engulfed the forecastle on a down-pitch; as the bow lifted, the upward acceleration of the mass of entrained liquid developed forces which deformed the forecastle deck and lowered the bulwarks outboard.

Apparently the deck drainage afforded by line-handling openings in the bulwark is inadequate to cope with this problem. One interpretation might be to eliminate the bulwark and provide a considerable amount of camber to the forecastle deck. If the bulwark is required as a spray shield in less severe weather, it might be replaced by rows of spray-deflecting slats which would permit more rapid drainage of the forecastle. The same approach might be considered in areas of the main deck abaft the forecastle to provide protection for deck cargo -- particularly in the case of container ships.

The instance where a tanker incurred damage to plating and structure around its hawse pipe prompts a precautionary note relative to structural design in the bow region. A rigid element such as this can create a hard spot which restricts flexing of the structure in response to heavy weather impacts. This can result in localized damage in the area where the rigid element is attached. Excessive stiffening of the forefoot or the forecastle deck could have a similarly undesirable effect.

CONCLUSIONS AND RECOMMENDATIONS

It has been shown, even from the limited quantity of casualty data obtained, that significant trends of structural failure are evident. From the data evaluated in this survey it has been possible to draw a few conclusions as to damage related to heavy weather at sea and the relative susceptibility of various ship structures to damage from collisions with fixed and mobile structures.

Although these trends are significant, they have not yet been sufficiently validated to recommend and justify specific structural modifications. It is believed, however, that a more thorough examination of the casualties which produced these trends would be of value. Particularly in cases of slamming damage, and to a lesser extent cases involving damage to the forecastle and weather deck, it would be possible to attain a better understanding by further examination of the environmental conditions and of the hull form and above water configuration in the bow area of each ship involved.

In cases of collision casualties it appeared that the damage centered in the weaker regions of the hull structure. But these damage concentrations were also logically related to operational factors associated with ship handling in restricted waters. The understanding of cause and effect in collision casualties could be markedly improved by adding more tanker collision casualty data to the data base. The longitudinal framing of tankers appears to be inherently more resistive to damage of this type and thus, if structural changes can indeed reduce the extent of collision damage, this would become apparent in analyses of such an expanded collection of data. Such additional data on tanker casualties are available in the files of the U. S. Salvage Association.

Any statistical summary of a mass of data has both advantages and limitations. The statistical approach can aid in pointing out areas of damage attributable to specific causes and the physical extent of such damage. The greater the mass of data the more is the authority with which the finger can be pointed at areas of deficiency; thus there is a strong tendency to perpetuate any data collection and analysis program. However, in this particular case, it is believed that continuation is warranted. At present it is evident that the data collection and analysis program has yielded information of specific value as related to certain types of structural damage. With the assimilation of additional data it will be possible to learn more about these specific types of damage and to isolate other types of damage which occur frequently in various classes of ships.

The data form, Figure 1, derived as a part of this study is generally adequate to record the maximum amount of information available from known sources of casualty data. Although the form provides for numerous entries related to the extent of damage, the applicable information is seldom provided in casualty reports. One addition to the form is suggested which would make the data more meaningful in this regard -- the cost of repairs. Cost would be used not as an economic index but as an analytical weighting factor as a means to assess the extent of damage.

It is also concluded that, while statistical analyses of the accumulated data are valuable and should be continued, the ultimate worth of studying casualties is highly dependent upon an engineering evaluation of all casualty situations. From a design viewpoint it is essential that cause and effect be isolated and categorized so as to determine what aspects are design functions and what aspects are outside the realm of the designer. In this sense the designer's realm includes such elements as propulsion and maneuvering control, hull configuration, and arrangements as well as the hull structure itself. These design elements are all interrelated in the performance of a ship and must be treated together when examining how total performance can be improved both technically and economically. Thus casualty data analyses should be undertaken by competent engineers who are aware of all design elements and who have a reasonable understanding of the many complexities of ship operation. When examining casualty data they should have access to pertinent design details of the ships involved, including hull lines and machinery arrangements as well as structural plans.

A final recommendation on the continued collecting and analysis of ship casualty data is that the process be expanded to include all data available for the last fifteen years and that the process then be kept current as new casualties occur. In this way a solid base of fundamental data will be in hand against which new data can be compared. It then may be possible to spot deficiencies in specific ship designs in time to recommend corrective action while those ships have useful life remaining. Furthermore, over an extended period, it will be possible to evaluate the success or failure of specific modifications. This eventually will provide a powerful tool for improving the economic performance of ships of the U. S. Merchant fleet.

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13. ABSTRACT

A limited investigation, conducted to determine the availability of data on ship casualties involving structural damage, revealed 824 applicable cases. A method was devised for reducing reported casualty data into a format adaptable to automatic tabulation and analysis. Collision with fixed and mobile structures was found to be the predominant cause of structural damage; heavy weather damage to the forefoot and forward weather deck also occurred with significant frequency. Patterns of damage frequency and location existed on a number of classes of ships. These have been interpreted to indicate how structures could be altered to reduce the damage sustained. Recommendations are made to continue the data collection and analysis program and to investigate more extensively the ways in which significant structural design information can be extracted.

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